Direct detection of neutralino dark matter and b $\rightarrow$ sγ decays *

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We analyze the direct detection rate of minimal supersymmetric neutralino dark matter in germanium, sapphire and sodium iodide detectors, imposing cosmological and accelerator bounds including those from b $\rightarrow$ sγ decay. In contrast with several other recent analyses we find models with light charged higgsinos and large stop mixing in which the counting rate in solid state detectors exceeds 10 events/kg/day.

The recent observation of the b $\rightarrow$ sγ decay [1] has stirred interest in the possible bounds obtainable for supersymmetric models that contribute to this process [2–4]. Some authors [5,6] analyzed the consequences of this and other accelerator bounds on the predicted rates in experiments searching for neutralino dark matter in the galactic halo. They claimed that allowed rates are small, largely irrelevant for present-day dark matter detectors.

We performed a detailed study of the allowed supersymmetric parameter space. In contrast with [5], we found models in which the integrated counting rates are not at all small but as high as to have already been probed (and excluded) by current negative dark matter searches. Here we present an overview of our approach and results, and refer the reader to [7] for further details.

We work in the framework of the minimal $N = 1$ supersymmetric extension of the standard model (MSSM) [8]. We include one-loop radiative corrections in the Higgs sector according to the effective potential approach. For simplicity, we make a simple ansatz of a universal (weak-scale) sfermion mass parameter $m_{\tilde{f}}$. This ansatz implies the absence of tree-level flavor changing neutral currents in all sectors of the model. Our remaining arbitrary parameters are the soft supersymmetry breaking trilinear couplings A_b and A_t, the ratio of the two Higgs vacuum expectation values $\tan\beta$, the pseudoscalar mass m_A, the higgs(ino) mass parameter μ and the gaugino mass parameter M_2. We fix the top quark mass at $m_t = 175$ GeV. We note that this definition of the MSSM models is the same as in [5].

We adopt a phenomenological approach and allow for general variations of parameters in the MSSM, still of course consistent with experimental bounds and giving correct low-energy symmetry breaking. We keep only models that satisfy accelerator constraints, including the 95% C.L. limits on the b $\rightarrow$ sγ branching ratio from the CLEO experiment [1], $1.0 \cdot 10^{-4} <$ BR(b $\rightarrow$ sγ) $< 3.4 \cdot 10^{-4}$. We calculate BR(b $\rightarrow$ sγ) according to [2]. For a general supersymmetric model, b $\rightarrow$ sγ receives contributions from W-bosons, charged Higgs bosons, charginos, gluinos and neutralinos. For our no-FCNC ansatz, the latter two are absent. We also impose the cosmological constraint $\Omega_\chi h^2 < 1$, where the relic neutralino density $\Omega_\chi h^2$ is calculated as in [10].

We compute direct detection rates, integrated over deposited energy with no energy threshold, for pure germanium (^{76}Ge), sapphire (Al_2O_3) and sodium iodide (NaI) detectors. For the local galactic neutralino velocity distribution we assume a truncated gaussian of velocity dispersion

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120 km/s. We fix the relative Earth-halo speed at 264 km/s (a yearly average). We adopt a local dark matter density of 0.3 GeV/cm^3 whenever $\Omega_\chi > \Omega_{\rm gal}$, the minimum value for which neutralinos could make up the totality of galactic dark matter. When $\Omega_\chi < \Omega_{\rm gal}$, we scale the local density proportionally to $\Omega_\chi/\Omega_{\rm gal}$. We use a heavy-squark effective lagrangian [11] for the neutralino-nucleon interaction, and we use simple gaussian nuclear form factors [12], which are quite adequate for our purposes.

We produce two initial samples of 4000 points each, generating model parameters randomly within the following bounds: $m_{\tilde{f}} \in [100, 3000]$ GeV, $A_b, A_t \in [-3m_{\tilde{f}}, 3m_{\tilde{f}}]$, $\tan\beta \in [1.2, 50]$, $m_A \leq 1000$ GeV, and, for the first sample, $\mu, M_2 \in [-5000, 5000]$ GeV, while for the second sample we trade μ, M_2 with the lightest neutralino mass $m_\chi \in [-5000, 5000]$ GeV and its gaugino fraction $Z_g \in [0.00001, 0.99999]$. In these samples, we find *no* points with interesting detection rates, say above 1 event/kg/day in Ge. But we notice that the distributions of points obtained depends crucially on our choice of sampling. So we do not conclude that in our class of models the b $\to$ sγ constraint is so strong to exclude interesting detection rates. We instead perform two special scans aiming at large neutralino-proton cross sections. In the first, we sample in μ–M_2 as before but restrict $m_A \in [0, 60]$ GeV. In the second, we sample in m_χ–Z_g with the restricted m_A range and further demand $m_\chi \in [800, 1200]$ GeV and $Z_g \in [0.01, 0.99]$. The results of these special scans for Ge, Al_2O_3 and NaI are shown in fig. 1, together with (the top parts of) the initial naive samplings. Remarkably, the high-rate zones, empty in the initial scans, are now filled with points. Particularly striking is the concentration around $m_\chi \simeq 1000$ GeV, which obviously comes from the second special sampling.

Therefore, contrary to [5], we find models that do not violate the experimental and cosmological constraints mentioned above and in which, thanks to a light neutral Higgs boson, the integrated counting rate is as large as 10 events/kg/day in Ge and even 100 events/kg/day in NaI. These models have a relatively light (100–200 GeV) charged Higgs boson, but they are compatible

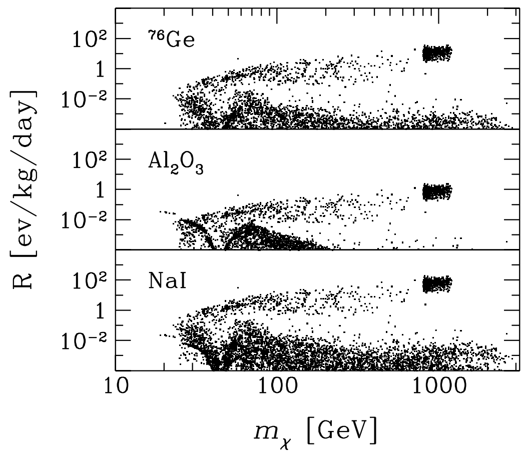

Figure 1. Integrated direct detection rate R in ^{76}Ge, Al_2O_3 and NaI detectors versus neutralino mass m_χ.

with the b $\to$ sγ constraint because the charged Higgs contribution to the b $\to$ sγ amplitude is effectively canceled, at large $\tan\beta$ and large top squark mixing, by the contribution from a light charged higgsino (cfr. [4]). In terms of the supersymmetry parameters this occurs when $|M_2| \gg |\mu| \gtrsim m_W$ and $\mu(A_t + \mu\cot\beta) < 0$. We can satisfy these conditions for both positive and negative values of μ, because we are free to choose the sign and magnitude of A_t. This freedom would be lost in models imposing additional theoretical constraints, for example in no-scale models or in models with a flat Kähler manifold ($A = 0$ or $A = B - m$ respectively at the unification scale).

In our simple-minded prescription for the local galactic neutralino density, the value of $\Omega_{\rm gal}$ is quite uncertain, both because of uncertainties in the density and extension of galactic halos and because of the poorly known relation between the universally-averaged and the local dark matter densities. Fig. 2 shows the predicted rates in Ge versus the calculated neutralino relic density $\Omega_\chi h^2$. The two initial samples show at the bottom and the two special samples are the band and cloud in the upper parts. Models with $\Omega_\chi h^2 > 1$ are plotted only to illustrate the trend of R versus $\Omega_\chi h^2$. Rates to the left of the vertical dashed

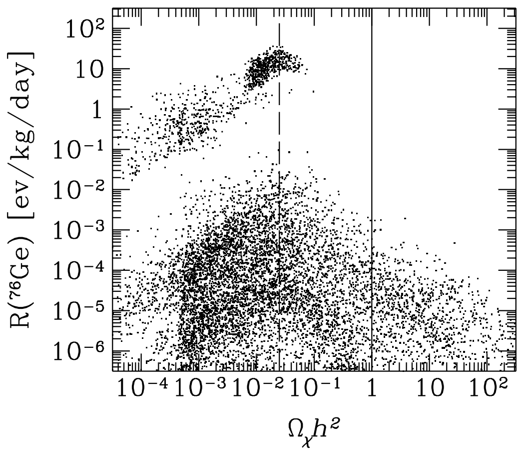

Figure 2. Integrated direct detection rate R off ^{76}Ge versus neutralino relic density $\Omega_\chi h^2$.

line ($\Omega_\chi = \Omega_{\rm gal}$) are Ω-suppressed. We have chosen $\Omega_{\rm gal} h^2 = 0.025$, as in [5], but the actual value might be even one order of magnitude larger or smaller. Were it smaller, many models in which the detection rate is suppressed just because $\Omega_\chi h^2$ is too small would have important detection rates. Notice that in some of the interesting models, the neutralino relic density is large enough for them to fill up galactic halos.

We stress that the density of points in the plots depends on the *a priori* distribution of the model parameters, which is entirely at our choice. One should not be misled in thinking that rate values in zones where there are more points are more probable than those in which there are few. This is evident for our special scans, for which high detection rates with acceptable b $\rightarrow$ sγ branching ratios look "generic." No probability should be attached to the plotted point distributions or to histograms derived from them: the figures can only illustrate possible neutralino detection rates.

The conservative approach we propose is to regard the whole range of outcomes of a calculation as a priori equally probable, irrespective of the parametrization. This means that really only upper and lower limits can be given. Unfortunately, a thorough and fine scanning of parameter space is computationally very expensive and an alternative analytical extremization seems prohibitively complicated. We therefore have to leave the following question open: are there in fact additional, allowed points in the empty regions of our plots?

REFERENCES

1. M S Alam et al (CLEO Collaboration), Phys Rev Lett 71 (1993) 674; Phys Rev Lett 74 (1995) 2885.
2. S Bertolini et al, Nucl Phys B353 (1991) 591.
3. R Barbieri, G F Giudice, Phys Lett B309 (1993) 86; V Barger, M Berger, R Phillips, Phys Rev Lett 70 (1993) 1368; J L Hewett, Phys Rev Lett 70 (1993) 1045; Y Okada, Phys Lett B315 (1993) 119.
4. R Garisto, J N Ng, Phys Lett B315 (1993) 372.
5. F M Borzumati, M Drees, M M Nojiri, Phys Rev D51 (1995) 341.
6. P Nath, R Arnowitt, Phys Lett B336 (1994) 395; Phys Rev Lett 74 (1995) 4592.
7. P Gondolo, L Bergström, Oxford University preprint OUTP-95-38P, hep-ph/9510252.
8. H E Haber, G L Kane, Phys Rep 117 (1985) 75; J F Gunion, H E Haber, Nucl Phys B272 (1986) 1 [Erratum-ibid B402 (1993) 567].
9. L Montanet et al (Particle Data Group), Phys Rev D50 (1994) 1173.
10. P Gondolo, G Gelmini, Nucl Phys B360 (1991) 145; P Gondolo, in preparation.
11. K Griest, Phys Rev D28 (1988) 2357; R Barbieri, M Frigeni, G F Giudice, Nucl Phys B313 (1989) 725; G Gelmini, P Gondolo, E Roulet, Nucl Phys B351 (1991) 623; M Kamionkowski, Phys Rev D44 (1991) 3021; A Bottino et al, Astropart Phys 2 (1994) 77.
12. A Gould, Ap J 321 (1987) 571; J Ellis, R Flores, Nucl Phys B307 (1988) 883; Phys Lett B263 (1991) 259; J Engel, P Vogel, Phys Rev D40 (1989) 3132; J Engel, S Pittel, P Vogel, Int J Mod Phys E1 (1992) 1.